Overview of the CALICE AHCAL Analysis

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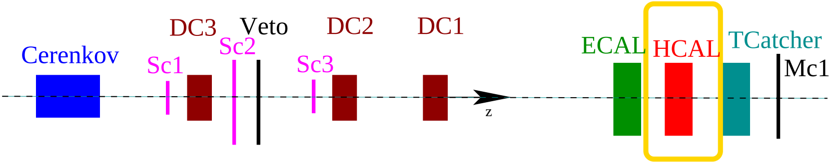
(on behalf of the CALICE collaboration)

Calorimeter for ILC

Overview

Introduction

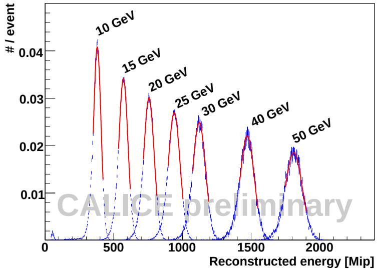
- **CALICE collaboration**: major R&D effort to develop performant detectors for high energy e^+e^- experiments ($\sim$ 280 peoples)
- **Test beam programme**:
  - ECAL: scintillator, SiW
  - **HCAL: analog (scintillating tiles and SiPMs)**, digital (RPCs)
  - TCMT (tail catcher and muon tracker)

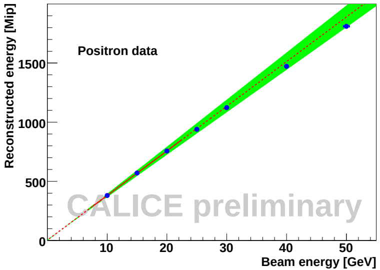


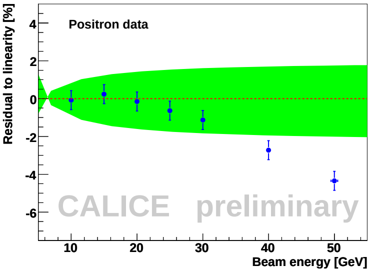
- AHCAL analysis focus: AHCAL (+TCMT)
- **Electromagnetic** showers: without ECAL in front
- **Hadronic** showers: contained or not in the AHCAL, use ECAL as tracker
- Results with CERN 2007 data

Electromagnetic Analysis

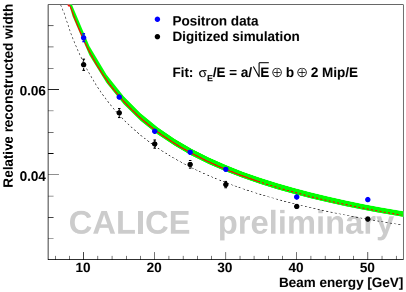
- Used to validate calibration procedure and Monte Carlo digitisation
- 10-50 GeV e^+ data
- Linearity of calibrated calorimeter response $\sim$ 4% at 50 GeV







Electromagnetic Analysis - continued



- **Stochastic term**:

  Data: $a = (22.6 \pm 0.1_{fit} \pm 0.4_{calib})\%$

  MC: $a = (20.9 \pm 0.3_{fit})\%$

- **Constant term**:

  Data: $b = (0 + 1.4_{fit} + 0.3_{calib})\%$

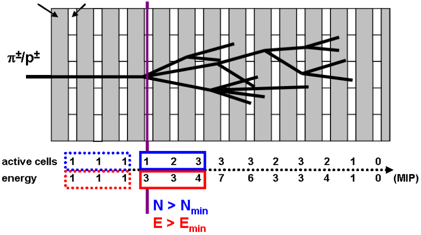
  MC: $b = (0 + 2.2_{fit})\%$

- **Noise term**: fixed to 2 MIPs (from random trigger events)

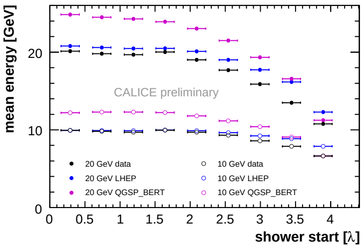
$\Rightarrow$ The agreement of MC with data on electromagnetic scale sufficient for hadronic analysis (remaining deviations less than 10%)

Hadronic Analysis: Shower Starting Point

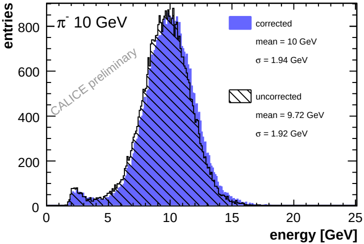
- Determine start of shower from increase of number of active tiles and energy in AHCAL layers (precision $\sim$ 1 layer)



- Effect of leakage more severe for increasing beam energies:

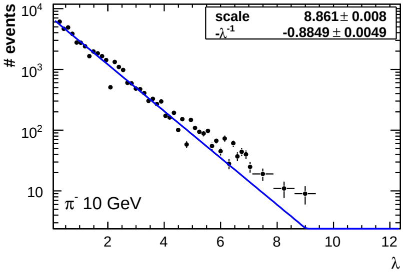


- Total energy before and after leakage correction:

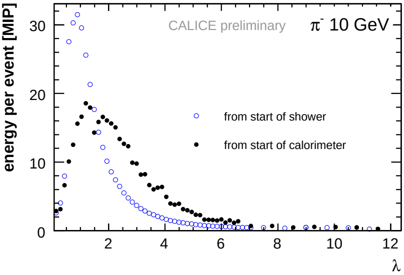


Hadronic Analysis: Shower Starting Point

- Distribution of position of shower start in AHCAL as a function of λ_I has the expected exponential fall:



- Longitudinal shower profile much shorter after correcting event-by-event for the variation of the shower starting point:

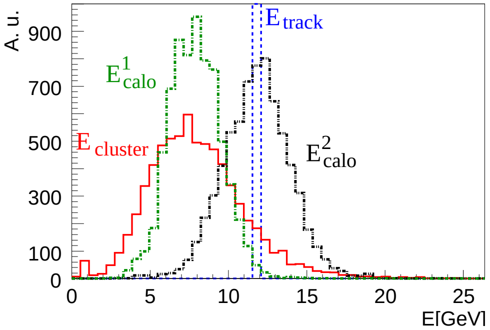


Hadronic Analysis: Particle Flow

- Ultimate goal of highly granular calorimeter: separate showers in a single event

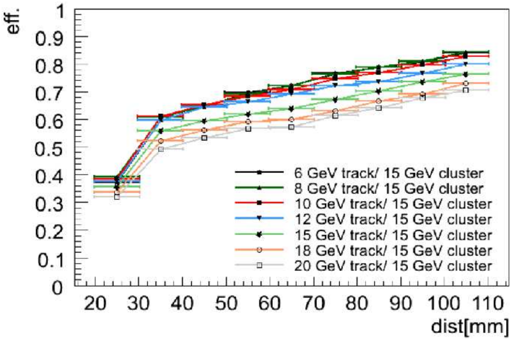
To test quality of shower separation:

- Overlay 2 single pion events
- Use track-wise algorithm to reconstruct clusters (E^1_{calo}, E^2_{calo})
- Assume one of the clusters belongs to a charged particle, i.e. known momentum (E_{track})
- Assume second cluster is neutral
- Sum clusters to form a PFlow reconstructed object: $E_{PFlow} = E_{cluster} + E_{track}$



Hadronic Analysis: Particle Flow Efficiency

- For events where exactly 2 clusters were found, **efficiency** of shower separation: $eff = \int_{-3\sigma}^{3\sigma} E_{cluster} / \int_{\infty}^{\infty} E^1_{calo}$

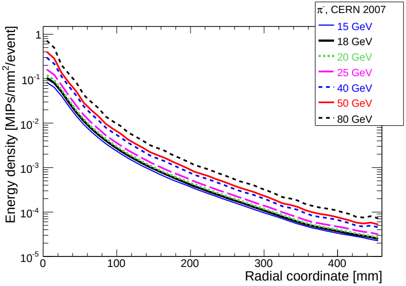


Efficiency increases:

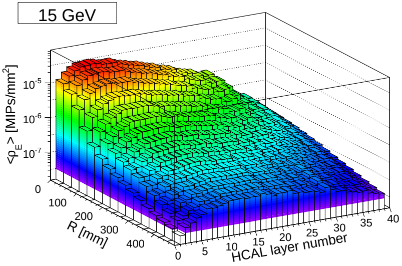
- for larger distances between particles
- for lower energies of the two particles to be separated

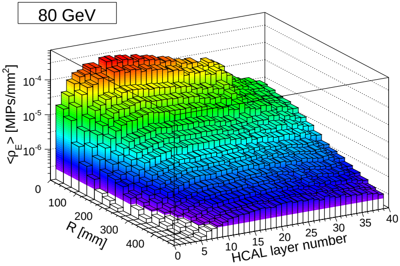
- PFlow tested for separations up to 11 cm only
- Analysis of Fermilab data ($\sim$ 150 millions events), with separations up to 20 cm, to come

Hadronic Analysis: Transverse Profiles



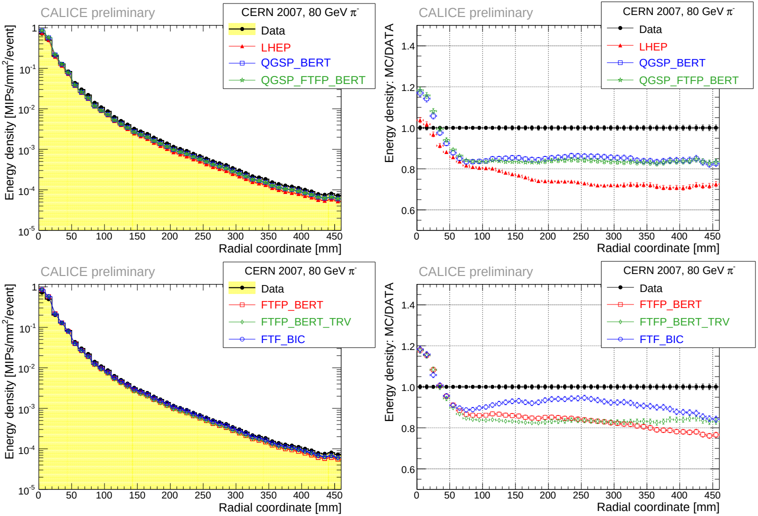
- Shape of transverse profile independent of energy, as expected
- Two-dimensional view in the lateral and longitudinal development





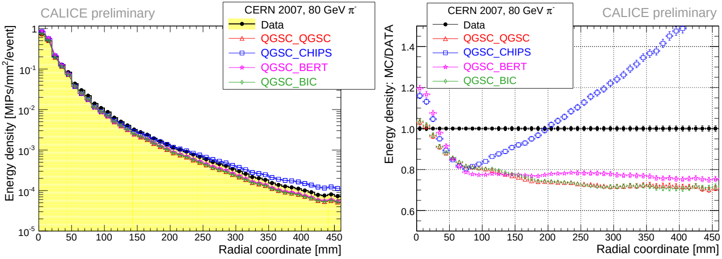
Hadronic Analysis: Transverse Profiles

- Comparison with different GEANT4 models in order to exclude outliers



Hadronic Analysis: Transverse Profiles

- QGSC_CHIPS model has more neutrons than in other physics lists; very different behaviour

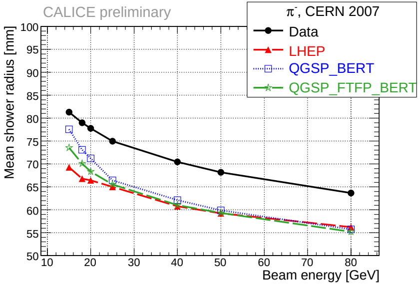


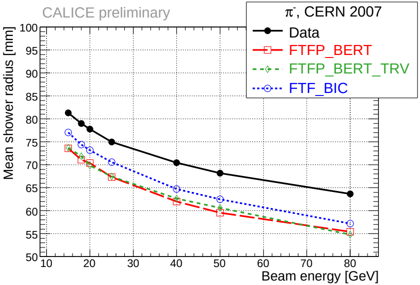
- In general, agreement between data and MC around 20%
- In most cases, MC above data in shower core, but below in the tails (not clear if this is due to detector geometry or something else)

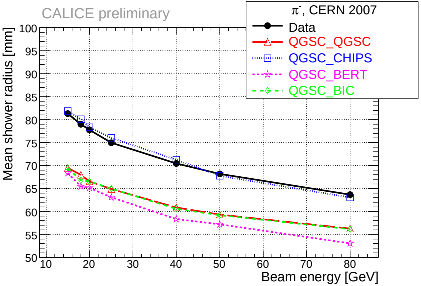
- Caveat: QGSC_CHIPS, QGSP_FTFP_BERT and FTFP_BERT_TRV models available only in GEANT4 9.3beta version, i.e. under development

Hadronic Analysis: Shower Transverse Width

- **Shower radius**: distance of an AHCAL hit to the shower axis, weighted with the energy
- Showers become narrower with increasing energy







Conclusions

- CALICE AHCAL sucessfully operated in test beams at CERN 2006/07, Fermilab 2008/09
- Results from electromagnetic analysis validate the MC digitisation
- Linearity up to 4% (and improving), sufficient for hadronic analysis
- Hadron showers are complex, and so is analysing/understanding them:
  - Thanks to **high segmentation**, it is possible to use algorithms for correcting for the shower starting point (benefit for energy resolution still to be seen)
  - Methods of cluster/shower separation as needed for **particle flow** measurements developed; to be extended at larger separations with Fermilab data
  - Basic shower profiles and properties studied and compared to MC
  - On-going discussions with GEANT4 experts in order to find the best observables for **MC validation**
  - In the moment, MC to data agreement around 20% (depending strongly on the model, incoming hadron energy, studied variable)
- Continuous pursue for better understanding of our data leads to better calibration constants, better MC implementation
- Stay tuned, more to come from CALICE AHCAL